# A Study of Evaluation Index and Level for Real-Time Bus Arrival Information Reliability

**Dongwoo SHIN**
Manager
*Development Team/ITS, SK C&C*
*SK u-Tower, 25-1, Jeongja-dong,*
*Bundang-gu, Seongnam-si*
*463-844 KOREA*
*Office : +82-2-6400-3239*
*E-mail : koball@naver.com*

**Kyungwoo KANG**
Professor
*Transportation Engineering*
*University of Hanyang*
*Sa-3dong, Sangrok-gu, Ansan*
*425-791 KOREA*
*Fax : +82-31-406-6290*
*E-mail : kyungwoo@hanyang.ac.kr*

**Wookag KOOK**
Ph.D
*Transportation Engineering*
*University of Hanyang*
*Sa-3dong, Sangrok-gu, Ansan*
*425-791 South KOREA*
*Fax : +82-31-406-6290*
*E-mail : trkw@lycos.co.kr*

**Abstract**

As a part of a public transportation information provision, the Bus Information System (BIS) provides bus arrival information and bus location information to users. The reliability index and level are evaluated differently in each city. As the evaluation is performed, without considering prediction size and range, the evaluation result cannot be fed back to the BIS. Therefore, this study derived time range and spatial range of bus arrival information based on the results of a survey. 'User allowed range' and ‘User allowed error' can be selected as the range of the evaluation and the level of the evaluation. The accumulation probability of the absolute error can be selected as the reliability evaluation index. Thus, this study showed the methods of selecting evaluation range, index and level for the evaluation of real-time bus arrival information reliability.

***Key Words:*** *BIS, real-time bus arrival, reliability evaluation, absolute error*

## 1. INTRODUCTION

The bus information system (BIS), which has been recently established in South Korea as a link to provide public transportation information, makes it possible to follow and collect the location of the bus that is operating along the existing route. Then it provides the forecasted bus arrival time and location information to the user. Currently, the BIS and the bus management system (BMS) are being operated in 28 locations in Korea to improve public transportation use. A public transportation user primarily acquires bus arrival information and the current location of the bus from the BIS.

The bus arrival information is provided for the passenger at the stop, and its reliability and passenger satisfaction change on a large scale according to the accuracy of the information. Thus, the development of a prediction algorithm, analysis and removal of error, and a variety of other studies are being advanced to improve the reliability of the information. Nevertheless, the basic error inevitably occurs because of the predicted information features. Therefore, an index and scope, which evaluate the reliability, must be defined, and the value of standard error is also required to provide information to the user. Thus, the measured index, scope, and error can provide useful feedback that will improve user satisfaction.

In many current studies, the reliability index for the bus arrival information assumes a normal error

distribution and uses the average of the absolute error. Although the distribution follows a normal distribution, applying the average of the absolute error cannot represent the characteristics of the error distribution because it does not consider the error variation.

In this paper, we analyze the features of the probabilistic error distribution for the estimated bus arrival time to set a new index that measures reliability. In addition, we derive timely scope of information and the level of error that satisfies the user, so that they are within user-friendly bounds. We consider creating the level and scope, which evaluate the reliability for the bus arrival information, and present the application alternative by deriving the index, range and standards.

## 2. INVESTIGATING THE LITERATURE

The BIS is the system that allows bus locations to be available in real-time by applying wireless communication and spearhead location technology, and provides the operational and present bus condition to users and the manager.

Jan-Willem Grotenhuisdhl et al. (2006) studied the level of public transportation for users' needs for IMTI (Integrated Multimodal Travel Information). They analyzed the types of required information depending on trip steps and ages, and the level of demand by evaluating quality of information services by taking a user survey of public transportation. As a result, the most needed information for users at bus stops or wayside is real time information and real time delay information to save their time and effort.

TCRP Report 100 (2003) shows that user recognize the delay time at bus stop, in the bus, for transfer and initial wait time differently.

Table 1 Relative Importance of Travel Time Components for Work Trips

| | In-vehicle Time | Walk Time | Initial Wait Time | Transfer Time |
|---|---|---|---|---|
| Average | 1.0 | 2.2 | 2.1 | 2.5 |
| Range | 1.0 | 0.8-4.4 | 0.8-5.1 | 1.1-4.4 |

Ko Seung Young classifies the BIS into two forms of information: bus locations and expected arrival times. In particular, he derives the factors that affect the optimal expected arrival times.

- Punctuality of bus operation or operating time distribution
- Accuracy of predicting bus arrival time
- Attitude of user waiting at stop
- Bus's operation strategy when a gap between the real and scheduled time occurs

Kim Seung Il et al. (2006) find that generating bus arrival information errors is unvoidable in processing, and stipulate it as 'system error'. Then, they arrange the system error that can occur and derive the statistical average; thus, they present a method to correct bus arrival information.

In the previous studies, people assume that the accuracy of algorithms is 100%, then present the cause of error or handle it as an error that occurred during the collection, processing, or provision periods. This is because the bus's location changes in real-time.
However, these types of error cannot explain all of the bus arrival information errors.

## 3. ANALYSIS PROCEDURE

### 3.1 Outline

The needed factors to evaluate reliability of bus arrival information consist of evaluation range, index and standards. The evaluation for bus arrival information is done by using the absolute error, which is a gap between the real arrival time and expected arrival time. The absolute error of the bus arrival information generally increases as the expected value arises, and it follows a probability density distribution. In the previous evaluation method, absolute error incurred over the course of a day is applied for the evaluation index. This index represents a high level of reliability when the expected

value is smaller than the true value; otherwise, it shows a low level of reliability. To compensate, an error rate is applied. In this case, however, the error rate is high when the expected value is smaller than the true value; otherwise it has a low level of reliability. Hence, we cannot know the size of the error. In other words, it is better to set the standards for reliability after selecting the prediction scope of the bus arrival information because it is profitable as feedback for the result of the reliability measurement.

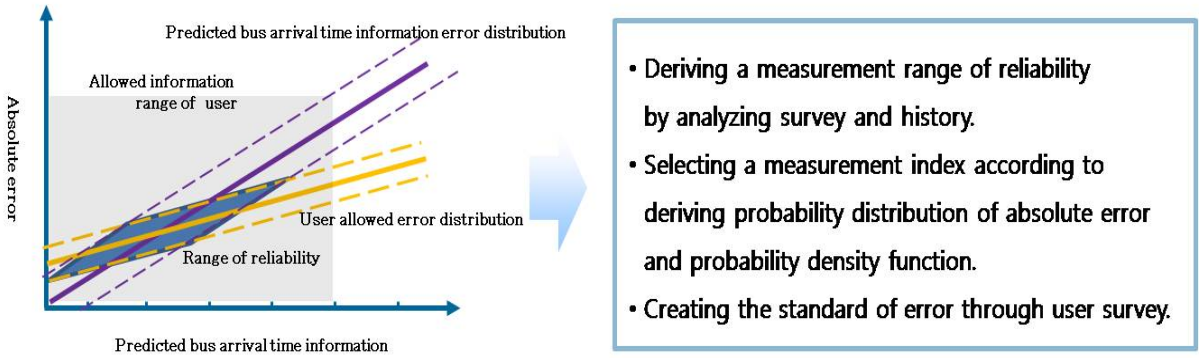


Figure 2 Outline for a way to study

In this paper, to derive an evaluation index that corrects the reliability evaluation methods for previous bus arrival information, the weaknesses of each previous evaluation provision for reliability are considered and presented in Table 2.

- Absolute error follows various probability density distributions, not a normal distribution, and the distribution changes as a function of time.
- User allowable error for standards of evaluation also follows a probability density distribution, which is expected to vary randomly.
- Thus, expected probabilistic value could be derived by considering each probability density function.

Table 2 Analysis ways of bus arrival information

| Evaluation factors | Weakness of previous evaluation method for reliability | Analysis ways |
|---|---|---|
| Index | ● Applying the average value of absolute error and error rate<br>● Assuming the absolute error with normal distribution<br>● Disable to recognize error's size when applying error rate | ● Applying the accumulated probability by deriving probability distribution of the absolute error |
| Range | ● There is no standard range for time, space | ● Deriving measurement range through survey and history of providing information. |
| Standard | ● Free application | ● Deriving standard value of error through survey |
| Etc | ● Difficult to understand the result | ● Applying a single index |

### 3.2 Calculating Absolute Error

In this paper, arrival stop event data, which means utilizing the collected bus arrival information, is applied to a bus's real arrival time. In addition, the arrival stop event data is assumed to have 100% accuracy, and each bus's absolute error of bus arrival information could be calculated as the following.

Absolute error = |Predicted bus arrival time - Real bus arrival time|

The predicted absolute error for each separate bus is calculated by collecting expected bus arrival

information every 3 min. This is because the average movement time between bus stops in Anyang is 3 min. City routes and metropolitan routes are analyzed separately because the distributions of running intervals and arrival times are different.

### 3.3 Determining Evaluation Index for Reliability

To derive the evaluation index for reliability, we collect the data of predicted bus arrival information for every 3 min, then derive the absolute error for a unit of time.
The analysis of probability distribution for absolute error was done using the following procedure.

Step 1) Classifying the collected bus arrival information history into urban routes and the wide area routes

Step 2) Calculating the absolute error for each separate bus by collecting data every 3 minutes

Step 3) Deriving the suitable probability density function through the distribution of absolute error over time

Step 4) Calculating the expected value of cumulated probability for absolute error per unit of time

Step 5) Comparing and analyzing both previous and current evaluation methods for reliability

## 4. COLLECTION OF DATA

In this paper, to investigate the level of perception about bus arrival information in Anyang and demand for providing current information, we surveyed 200 people at main transfer stops in Anyang. (November 12-13, 2008)

This study is to determine the level of bus user demand for the BIS system. The factors, which affect the level of demand, consist of whether it is an urban trip or metropolitan trip, and the time of use. The composition of survey contents is mainly divided into general questions, questions for trip pattern and demand for BIS.

Table 3 Classification and objective of survey contents

| Classification | Survey contents | Objective |
|---|---|---|
| General | ● Gender<br>● Age<br>● Occupation | User's general information |
| Trip pattern | ● Objective for use bus | Investigating the objective of trip |
| | ● Use area (urban/metropolitan) | Investigating the section of trip |
| | ● Time range of use bus | Investigating the time range of trip |
| | ● The number of bus use | Investigating trip frequency |
| | ● Time to use bus | Investigating trip distance for time |
| | ● The number of transfer | Investigating whether transfer or not |
| | ● Time to wait at stop | Investigating the time to wait at stop |
| BIS recognition/ evaluation | ● BIS recognition | Investigating BIS recognition |
| | ● Demand for BIS information | Investigating demand for BIS information |
| | ● Accuracy for BIS information | Investigating accuracy for BIS information |
| Allowable range for BIS information | ● Max range of stop for BIS<br>● Max range of time for BIS<br>● Allowable error for BIS | Investigating the allowable range for BIS |

We analyze the distribution characteristics of absolute error to derive an index of reliability for evaluating bus arrival information. Then, we use the history for a day of provided bus arrival information which is collected from city A that is operating BIS. The stops for analyzing error

distribution of bus arrival time are selected from the urban center, which have uniform distance intervals. Then we collect the bus arrival time and arrival event information for that stop. As can be seen in <Table 4>, the bus operation interval and user characteristics for urban and metropolitan routes are different. Therefore, they are analyzed separately.

Table 4 Collected data feature of bus arrival information

| Classification | Contents |
|---|---|
| Date of collection | Weekday in November, 2008 |
| Time range | 24 hours |
| Stop | 1 stop at central urban |
| Route | Total urban:17, metropolitan:6 routes |
| Operation interval | 4~20mins, average 10mins |
| The number of sample | 16,405 |

## 5. ANALYSIS

### 5.1 User Allowed Range

#### 5.1.1 User Allowed Range Choice

According to the trip characteristic, after dividing the urban trip users and the metropolitan trip users, it analyzed user allowed range and allowed error for bus arrival information. The user allowed range of bus arrival schedule had a high frequency: 7-9 minutes for urban trip users and 10-12 minutes for metropolitan trip users. Spatial users allowed a range of bus arrival schedules such that the urban trip user has the information before 3 bus stops and metropolitan trip user before 5 bus stops.

The bus arrival information of urban route and metropolitan route users for the allowed range is compared to previous offers of bus arrival information. Subsequently, the result of the application of urban routes of 9 minutes and metropolitan routes of 12 minutes are the same in Table 5.

Table 5 Previous offers of bus arrival information within user allowed range

| Routes | User range | | Historic offers | |
|---|---|---|---|---|
| | classification of range | Range of information | The number of offers | range ratio |
| Urban | Time range | 9 minute | 11,978 | 85% |
| | Space range | 5 station | 11,314 | 82% |
| Metropolitan | Time range | 12 minute | 1,747 | 67% |
| | Space range | 7 station | 1,714 | 67% |

#### 5.1.2 User Allowed Error Choice

A 3 minute interval of bus arrival information is used on the supposition that the calculated user error is within the allowed range. In this case, the distribution of allowed errors is analyzed. The results follow a Uniform Distribution. The probability density function of dispersion normal distribution in each time interval is applied, and the result, which calculates a probability for expected error, is shown in Table 6.

<Uniform Distribution>

● Parameters

a, b - continuous boundary parameters ( a< b)

● Domain

$a \leq X \leq b$

● Probability density function

● Cumulative distribution function

$$F(x) = \frac{x - a}{b - a}$$

Table 6 User allowed error

| allowed error of urban trip user | | | | allowed error of metropolitan trip user | | | | |
|---|---|---|---|---|---|---|---|---|
| Cumulative probability | expectations error for the estimated time of bus arrival (second) | | | Cumulative probability | expectations error for the estimated time of bus arrival (second) | | | |
| | 1~3 (min) | 4~6 (min) | 7~9 (min) | | 1~3 (min) | 4~6 (min) | 7~9 (min) | 10~12 (min) |
| 3% | 45 | 45 | 45 | 3% | 43 | 43 | 60 | 60 |
| 10% | 60 | 60 | 60 | 20% | 60 | 60 | 60 | 60 |
| | | | | 30% | 60 | 60 | 60 | 120 |
| | | | | 40% | 60 | 60 | 60 | 120 |
| 50% | 60 | 60 | 120 | 50% | 60 | 60 | 120 | 120 |
| 60% | 60 | 60 | 120 | 60% | 60 | 60 | 120 | 156 |
| 70% | 60 | 120 | 120 | 70% | 60 | 60 | 120 | 180 |
| 80% | 60 | 120 | 180 | 80% | 60 | 120 | 180 | 228 |
| 90% | 120 | 180 | 240 | 90% | 114 | 174 | 180 | 300 |
| 100% | 600 | 540 | 480 | 100% | 600 | 600 | 600 | 600 |

### 5.2 Application Analysis for Bus Arrival Schedule of Reliability Evaluation Index

5.2.1 Derive A Distribution of Absolute Error for Bus Arrival Schedule

The error of bus arrival schedule is calculated as (prediction duration time - actual time of arrival). The bus arrival information of prediction time for 16,405 cases processed by the BIS of Anyang city was aggregated to data in 3 minute intervals. Then, the absolute error for each time interval was calculated, and each production probability distribution analyzed. The results were analyzed and found to follow the form of a Weibull Distribution, which is described as follows:

< Weibull Distribution >

α -continuous shape parameter (α >0)

β -continuous scale parameter (β>0)

γ -continuous location parameter $\gamma \leq x < \infty$

● Cumulative distribution function

$$F(x) = 1 - \exp\left(-\left(\frac{x - \gamma}{1}\right)^{\alpha}\right)$$

$$F(x) = 1 - \exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right)$$

● Probability density function

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)$$

$$f(x) = \frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}\exp\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right)$$

The analysis result for a probability distribution of bus arrival information aggregated to 3 minute intervals for both urban routes and metropolitan routes followed a Weibull Distribution. The probability distribution of each factor follows Table 7. When using this, the accumulation probability produced for each unit of time will have an accumulation probability. This accumulation probability could make full use of the reliability evaluation index. That is to say**,** the accumulation probability is the probability of this particular value for the value of error. Therefore, the cumulative reliability value of the probability of a larger system for the criteria to evaluate is high.

Table 7 Estimated probability distribution coefficient- Weibull Distribution

| unit | Urban routes | | | Metropolitan routes | | |
|---|---|---|---|---|---|---|
| | α | β | Number of data | α | B | Number of data |
| 3 min | 1.153 | 58.402 | 4832 | 1.2326 | 280.97 | 1195 |
| 6 min | 1.3212 | 95.274 | 4741 | 1.2652 | 417.19 | 525 |
| 9 min | 1.2949 | 108.52 | 2405 | 2.1649 | 502.34 | 253 |
| 12 min | 1.2161 | 117.58 | 1021 | 1.9054 | 536.67 | 334 |
| 15 min | 1.3823 | 139.32 | 352 | 2.7992 | 683.36 | 155 |

5.2.2 Analysis Results for The Reliability Measurement Index of Bus Arrival Information

The Weibull Distribution was used for 3 minute intervals of absolute error of bus arrival information. Subsequently, the calculated expected error is shown in Table 8 for urban and metropolitan routes. The expected absolute error of the reliability was calculated by computing the cumulative probability. This decides the standard of absolute error for the qualitative case; thus, there is a possibility to compare to the measurement standard. When this is used, there is a possibility of deciding the baseline value of the absolute error, which at each unit of time follows a reliability level.
As the result of the bus arrival information in Anyang, in the case of an urban bus line, a predictive value of the bus arrival information gets larger and larger: there is no big variation for an expected value of the absolute error. Otherwise, in the metropolitan route case, it is easily seen that the expected value of the absolute error increases as the predictive value increases. We can see the proportional expression between the expected value of the absolute error and the predictive value. This means that the reference value of the error should be changed in each time unit. Thus, special standards are applied to each time unit for reliability valuation; it can be done by using an analyzed allowed error in a user-allowed range.

Table 8 Expectation of absolute error for bus arrival schedule reliability in an urban route

| Urban trip bus | | | | Metropolitan trip bus | | | | |
|---|---|---|---|---|---|---|---|---|
| Reliability (Cumulative probability) | error for the estimated time of bus arrival (second) | | | Reliability (Cumulative probability) | error for the estimated time of bus arrival (second) | | | |
| | 1~3(min) | 4~6(min) | 7~9(min) | | 1~3(min) | 4~6(min) | 7~9(min) | 10~12(min) |
| 10% | 8 | 17 | 19 | 10% | 45 | 70 | 129 | 144 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 20% | 16 | 30 | 34 | 20% | 83 | 128 | 219 | 223 |
| 30% | 24 | 44 | 49 | 30% | 122 | 186 | 279 | 291 |
| 40% | 32 | 58 | 65 | 40% | 163 | 245 | 336 | 355 |
| 50% | 43 | 73 | 82 | 50% | 210 | 312 | 392 | 422 |
| 60% | 54 | 89 | 101 | 60% | 263 | 390 | 450 | 491 |
| 70% | 69 | 110 | 125 | 70% | 329 | 484 | 515 | 569 |
| 80% | 89 | 136 | 157 | 80% | 414 | 611 | 598 | 670 |
| 90% | 121 | 179 | 207 | 90% | 551 | 809 | 707 | 810 |
| 100% | 1106 | 538 | 495 | 100% | 1643 | 1573 | 1199 | 1213 |

### 5.3 Result of Evaluation Index and Standard Application

5.3.1 To Apply A User Allowed Error Standard

For reliability level estimation of the system, standard error for bus arrival information by user survey is applied to set up the user satisfaction level and select the expected error. For example, if the urban trip satisfaction is 90%, the expected error value for 90% satisfaction is 60 seconds between 1 to 9 min of the user allowed range, as shown in Table 9. Thus, when the expected error value distribution of the urban route applies, 1 to 3 min is 60% error standard, 4 to 6 min is approximately 40% error standard, and 7 to 9 min is the same as 4 to 6 min. Therefore, the reliability of the system is at 1 to 3 min about 60% is applied, respectively, at 4 to 6 min about 40%, 7 to 9 min about 40% can be, as 90% user satisfaction is achieved by 60 seconds. Therefore, to meet the criteria to 100% improvement on the level of work in parallel to the goal can be reached.

The plan, which uses the expected value of error obtained by analysis of the user-allowed error distribution for estimation value of the bus arrival schedule, will be able to be applied both ways:

- Selecting a standard error for the bus arrival schedule after selecting a user satisfaction level
- Measuring the trust level according to the bus arrival schedule error level

Table 9 Error probability of urban trip user and urban routes

| Cumulative probability | Expectation error of urban trip user (second) | | | Expectation error of urban route (second) | | |
|---|---|---|---|---|---|---|
| | 1~3min | 4~6min | 7~9min | 1~3min | 4~6min | 7~9min |
| 10% | 60 | 60 | 60 | 8 | 17 | 19 |
| 20% | 60 | 60 | 60 | 16 | 30 | 34 |
| 30% | 60 | 60 | 60 | 24 | 44 | 49 |
| 40% | 60 | 60 | 60 | 32 | 58 | 65 |
| 50% | 60 | 60 | 120 | 43 | 73 | 82 |
| 60% | 60 | 60 | 120 | 54 | 89 | 101 |
| 70% | 60 | 120 | 120 | 69 | 110 | 125 |
| 80% | 60 | 120 | 180 | 89 | 136 | 157 |
| 90% | 120 | 180 | 240 | 121 | 179 | 207 |
| 100% | 600 | 540 | 480 | 1106 | 538 | 495 |

Table 10 Error probability of metropolitan trip user and urban routes

| Cumulative probability | Expectation error of urban trip user (second) | | | | Expectation error of urban route (second) | | | |
|---|---|---|---|---|---|---|---|---|
| | 1~3min | 4~6min | 6~9 min | 10~12 min | 1~3 min | 4~6 min | 6~9 min | 10~12 min |
| 10% | 43 | 43 | 60 | 60 | 45 | 70 | 129 | 144 |
| 20% | 60 | 60 | 60 | 60 | 83 | 128 | 219 | 223 |
| 30% | 60 | 60 | 60 | 120 | 122 | 186 | 279 | 291 |
| 40% | 60 | 60 | 60 | 120 | 163 | 245 | 336 | 355 |
| 50% | 60 | 60 | 120 | 120 | 210 | 312 | 392 | 422 |
| 60% | 60 | 60 | 120 | 156 | 263 | 390 | 450 | 491 |
| 70% | 60 | 60 | 120 | 180 | 329 | 484 | 515 | 569 |
| 80% | 60 | 120 | 180 | 228 | 414 | 611 | 598 | 670 |
| 90% | 114 | 174 | 180 | 300 | 551 | 809 | 707 | 810 |
| 100% | 600 | 600 | 600 | 600 | 1643 | 1573 | 1199 | 1213 |

## 6. CONCLUSION AND FUTURE STUDY

### 6.1 Conclusion

In this study, the demand range of users is analyzed to maintain a certain level of satisfaction regarding the bus arrival information of the standard method for information dispersion and the BIS, which reflects this system evaluation.

As identified in the related literature, active BIS construction is advanced, but the index for a reliability evaluation and standard application are different in each situation. In the case of the applied index from the reliability evaluation applied to the average of simple absolute error, the result of the reliability evaluation according to the estimation value of the bus arrival information is not consistent. For that reason, the index is not suitable. Therefore, this study analyzes the survey results to derive the time range and spatial range of the bus arrival schedule. It is defined to the ‘user-allowed range’, and the error range that is within the `user-allowed error '.

According to the resultant user trip characteristics, a survey analysis gives the permitted limit of the urban user for buses that appeared in 7~9 and 10~12 minutes for metropolitan trip users. Further, the bus arrival schedule in the system is provided that maintains most of the estimates within the range. In addition, the allowed error in the urban user and the metropolitan user about bus arrival information were derived for 3 minute time intervals. The results show the dispersion over a normal distribution for each range, the error at 60 second leads to 90% user satisfaction. When the users find an estimated time of arrival, they will be able to interpret with the distribution with an expected error. When using this and the user reliability measurement standard of system is set, the allowable expected error value of the user it is provided, and there is a possibility of creating a standard that evaluates the system. Additionally, from the research about bus information prediction information, which applies in an existing error measurement index, did not apply MAE (Mean Absolute Error), which uses an absolute error average over the analytical time. Moreover, the probability distribution analysis of error appearing in form of a probability distribution, which is not the normal distribution, was visible. This in addition to the timely bus arrival information about error occurrences gives a result that produces an accumulation probability about the range and the standard to be applied to the reliability evaluation index. The bus arrival information provided from the BIS by the measurement standard is presented to evaluate the methodology.

Table 11 The selected result of reliability analysis index and standard for bus arrival schedule

| Evaluation elements | Analysis plan |
|---|---|
| index | The cumulative probability application by derived probability distribution of absolute error |
| range | The derived evaluation range by survey and history analysis of Information provision |
| standard | The derived error standard by survey |

These research results through the satisfaction of users can maintain the situation by setting goals, and accordingly evaluating the range and reliability standards. In addition, it will be able to be applied in the standard, which reflects system evaluation. Improving the system of evaluation will give results, or provide information, to adjust the scope and will be able to establish a strategic response. The accumulation of the probability of error distribution of bus arrival plan information with BIS measures reliability provides a comparison of the BIS reliability rival evaluations. Of course, the algorithm used by local governments or other environmental variables vary, depending on the absolute error as the probability distribution. Previous analysis attributes of each local government will be able to determine the distribution of absolute error. This modeling will provide the means to apply the method to the regular monitor ring tool of system reliability.

### 6.2 Future Study

This study carries out surveys by specific instance and error analysis of BIS. However, user characteristics and user trip characteristic for each case are too different, which is a limitation of this study: the survey results in Anyang city cannot be generalized. However, the area where the BIS user survey was carried out is certainly included for system evaluation. Therefore, when the item applies to the user satisfaction level as survey, the result is derived from the characteristics of each case.

In this paper, we perform a simply designed survey to derive the allowable error and range for public transportation users. Further studies will be helpful. The factor that most affects bus arrival information is the accuracy of the algorithm. There is no found correlation between its accuracy and the degree of difficulty. However, the algorithm can now be applied, though it was not possible before because of the limits of the system ability. It is due to development of the hardware and software ability. Therefore, further study to improve the accuracy of algorithm is needed. Finally, a deeper study of the evaluation method for reliability has to be accomplished. The method involves measuring user satisfaction and developing a model that reflects system improvement.

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